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ALFRED ELECTRONICS 897 COMMERCIAL STREET, PALO ALTO, CALIF.

TRAVELING WAVE TUBE AMPLIFIER

MODEL 5-6752

Serial No. 25

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TRAVELING WAVE TUBE AMPLIFIER
MODEL 5-6752

SPECIFICATIONS

Frequency Range:	1.0 to 2.0 Kmc/s
Traveling Wave Tube Type:	620-B (Sylvania Electric)
Gain (small signal): (at maximum power output):	33 db minimum 30 db minimum
Gain Adjustment:	0 to 25 db minimum gain reduction by adjustment of front panel ANODE voltage control from maximum to zero
Power Output:	1 watt minimum into 50 ohm load
Noise Figure:	35 db maximum
Spurious Modulation:	At least 35 db below output signal level
RF Impedance:	50 ohms
RF Connectors:	Type N female
Metering:	Helix current, Cathode current on 3" front panel meter, selected by front panel switch Helix voltage available at rear for checking with external precision voltmeter
Front Panel Controls:	ANODE voltage (0 to 100% of normal setting) HELIX voltage (500 to 800 volts) METER current switch
Power Supply:	All voltages except solenoid are regulated, including TW tube heater. Protective relay shuts off TW tube power upon helix overcurrent
Input Voltage:	105 to 125 volts, 60 CPS, approximately 620 voltamperes
Mounting:	Bench with perforated metal dust cover Recessed handle sides removable for mounting in standard 19" rack Height: 10 1/2" Width: 19" Depth: 15" from panel; 16 1/2" overall
Finish:	Panel, grey hammertone Sides, top and bottom, dark metallic grey
Weight:	85 pounds

SECTION I - GENERAL

DESCRIPTION

The ALFRED Model 5-6752 Traveling Wave Tube Amplifier is a stable, high gain, broad band, power amplifier of microwave signals in the frequency range of 1 to 2 KMc/s. It is a compact, versatile instrument consisting of a traveling wave tube, its focusing solenoid, and a power supply for all required operating voltages. Electrical protection is provided to prevent damage to supply or TW tube from misadjustment or failures. Thus the varied and unique traveling wave tube characteristics may be conveniently applied to laboratory and systems use. Some possible applications are:

1. Power amplification of wide band signal generator outputs or complex modulated RF signals.

2. Amplification of RF pulses with rise times as short as a few millimicroseconds.

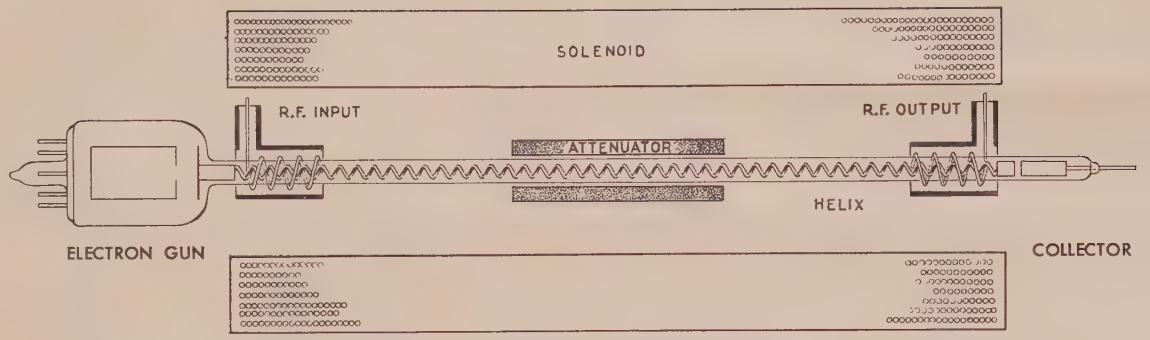
3. Isolation of a load from a microwave signal source.

4. Generation of extremely stable microwave oscillations either at fixed frequency or tunable over a wide range, using an external resonant feedback network.

On the front panel of the Model 5-6752 are provided type N fittings for RF input and output. Also provided are controls for anode and helix voltages to optimize performance for specific applications. A panel meter may be selected by a switch to monitor either helix or cathode current.

The TW tube requires no RF adjustment, is encapsulated for protection, and is easily replaced.

The Model 5-6752 is built as a convenient laboratory bench instrument. However, simply by removal of outside sheet metal sides, it may be mounted in a standard relay rack.



Schematic View of Traveling-Wave Tube

FIGURE 1

GENERAL DESCRIPTION OF TW TUBE

The traveling wave tube physical arrangement is indicated in Figure 1. The electron gun produces a beam of electrons which travels down the axis of the helical wire coil to the collector. The magnetic flux from the surrounding solenoid restricts the beam to travel axially along the tube just inside the helix. RF signals at low impedance are coupled to the helix at the electron-gun end and travel down the metallic path of the helix. The velocity of the electron beam is critically adjusted by the potential difference of the cathode and helix so that the beam velocity down the axis is just a little faster than the progressive RF signal on the helix. The field of the helix RF signal causes the electrons to bunch, so that at the collector end, their increased field returns to the helix an amplified signal which is coupled out through a low impedance device. Reflections down the helix are prevented by the attenuator, consisting of a lossy helix externally placed and positioned between input and output. Due to the low impedance of the coupling devices and the relatively long effective path provided by the TW tube, uniform amplification over a broad band of frequencies may be realized.

A more complete description and associated pertinent information are presented in the Huggins Laboratories General Information on Traveling Wave Tubes and Engineering Notes, at the end of this manual.

TW TUBE PEFORMANCE CHARACTERISTICS

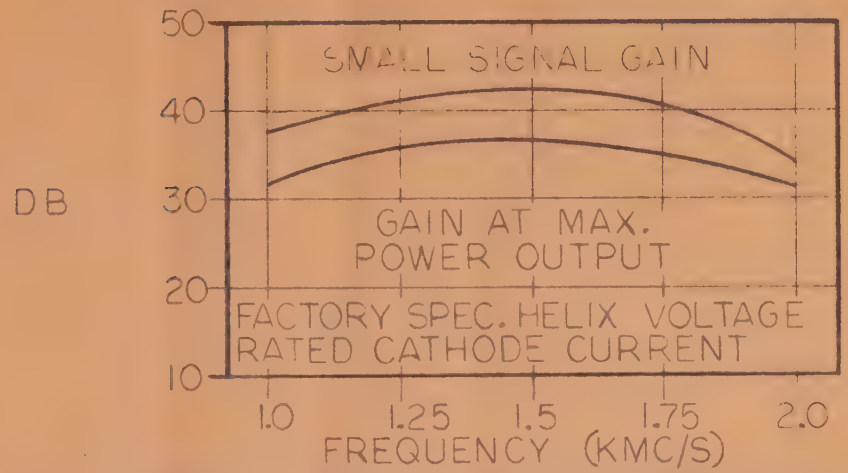
Gain and Power Output

Figure 2 shows typical curves of small signal gain, gain at maximum output, and maximum power output as a function of frequency. These curves are taken at a fixed helix voltage. The small signal gain is better than 33 db over the frequency range of 1 to 2 Kmc/s. Gain at maximum output is greater than 30 db over the same frequency band.

Power Output vs. Power Input

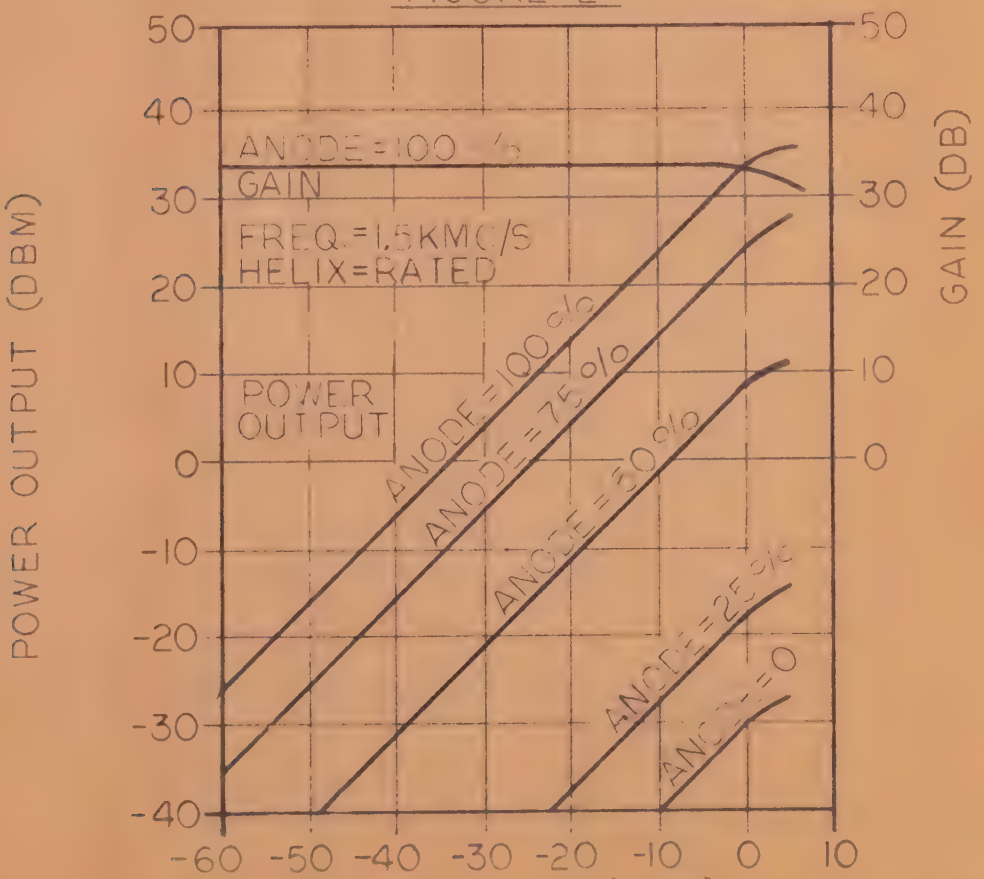
Figure 3 shows curves of power output vs. power input at mid-band, for several values of anode voltage. The anode is a low current electrode which controls beam current and hence gain and power output of the TW tube.

The anode curves exhibit the typical traveling wave tube characteristic, in that power output is a linear function of power input until the output level is about 6 db below maximum value. Beyond this the curve becomes non-linear, leveling off, and then decreasing as greater RF input is applied.



POWER OUTPUT AND GAIN VS. FREQUENCY

FIGURE 2



POWER OUTPUT VS POWER INPUT

FIGURE 3

Gain in db may be determined by subtracting the input power from the output, and is shown for 100% of normal anode voltage. Small signal gain remains constant with power input until power output starts to level off. At the power input corresponding to maximum output, gain has dropped approximately 6 db from the small signal value.

Power output and gain may be controlled by choice of anode voltage. Over 25 db change is possible by varying anode from 0 to 100%.

Noise Figure

The 6752 tube uses a parallel-flow Pierce gun, and only moderate effort has been taken to reduce noise figure. Over the frequency range of 1 to 2 KMc/s it does not exceed 30 db.

RF Load

The TW tube may be operated at any cathode current up to rated value into an RF load with a voltage standing wave ratio of 3:1 or less in the frequency range of 1 to 2 KMc/s. Performance will be stable without spurious oscillations, but output power will be less into mismatched loads.

POWER SUPPLY

1. An unregulated well-filtered solenoid current source providing approximately 90 volts at 3.5 amperes.

2. A magnetically regulated ac heater supply for the TW tube providing 6.3 volts regulated to 1%.

3. A magnetically regulated, well-filtered anode voltage supply providing 0 to 750 volts (maximum setting of panel control limited by an internal ANODE CALIB. control. Ripple does not exceed 200 mv pk to pk.

4. An electronically regulated Helix voltage supply providing 500 to 800 volts with 25 mv pk to pk ripple or less.

   An overcurrent interlock relay shuts off all high voltage should helix current exceed 2 ma for any reason. The interlock relay requires power switch to be turned off and then on again to restore high voltage.

FUNCTION OF CIRCUITRY

Referring to the circuit diagram, input power is applied to selenium rectifier SR1 through POWER switch SW1, SOLENOID fuse F1, and contacts of relay RY3. Direct current from SR1 is filtered by L1, C17, C18 and C19, and fed to focusing solenoid L2. A normally closed thermal switch mounted in L2 opens if its temperature exceeds 100° C. RY3 is thereby released and dc power to solenoid is removed. Excessive temperature may damage both TW tube and solenoid and could result from blower failure or abnormal ambient.

Power for transformers T1, T2, T3, and blower B1 passes through POWER switch SW1 and SUPPLY fuse F2. Note that indicator I1 is returned to the primary of transformer T1 so that when interlock relay RY1 is energized by contact closure of helix overcurrent relay RY2, the indicator and transformer T1 will both be de-energized. Helix overcurrent relay RY2 operates when the helix current exceeds 2 ma, to remove all high voltage from the TW tube. This protection is required should the electron beam strike the helix for any reason, such as misalignment or loss of solenoid current. Large beam current would overheat the fine wire of which the helix is formed, severely damaging it and driving out gas which would deteriorate cathode emission. Interlock relay RY1 is de-energized when POWER switch is turned off.

The voltage doubling rectifier arrangement of V1, V2, C1, C2, C3 and C4 produces approximately 1200 volts. This is fed through series regulating tubes V3 and V4, controlled by amplifier tubes V5 and V6, to obtain electronically regulated helix voltage. Reference voltage is developed across V7, V8, V9, and is compared with supply output voltage in differential amplifier V6. The amplified difference at the plates of V6 is applied to the cathode and grid of the left half of V5 by using the right half of V5 as a cathode follower. The difference voltage further amplified is then applied to the grids of series regulator tubes V3 and V4.

Output voltage is sampled by a resistor divider network consisting of precision resistors R11, R18, and potentiometers R10 and R19. Helix voltage is changed by varying the ratio of the divider network with panel HELIX voltage control R19. The HELIX CALIB. potentiometer R10 permits adjustment of the resistance ratio to compensate for slight differences in reference tube operating voltages. R10 is factory-set, using a 1/4% accuracy meter connected to the rear HELIX VOLTAGE terminals TP1 and TP2, to give panel HELIX control calibration within 2%.

Magnetically regulated ac voltage at the output of T3 is connected to ANODE CALIB. variable transformer T6 and panel ANODE variable transformer T7 in cascade. Output of T7 is fed to the primary of transformer T5. The secondary voltage of T5 is rectified by a full wave bridge rectifier consisting of SR3,4,5,6,7,8, and filtered by C15, L3 and C16 to produce low ripple dc TW tube anode voltage. Transformer T7 varies anode voltage from zero to a maximum value

in the range of 0 to 750 volts as determined by the setting of ANODE CALIB. transformer.

The regulated 115 volt ac output from T3 is also rectified by SR2 and filtered by C6 to obtain approximately +100 volts relative to zero line for V3 and V4 screen grids.

The TW tube helix is connected to its supply through Helix Overcurrent relay RY2. Should RY3 be removed from its socket, the coil or M1 open circuit, neon lamp V14 limits voltage across capacitors C9 and C10 to about 70 volts maximum, thereby preventing application of full helix supply voltage. METER switch SW1 selects either TW tube helix or cathode current to pass through M1.

Emission from the cathode of the TW tube varies heater power changes. Constant TW tube heater voltage is supplied by regulating transformer T3 and filament transformer T4. This also gives longer heater and cathode life by eliminating overvoltage operation. A second filament winding on transformer T4 provides invariant heater voltage from amplifier tubes V5 and V6 to improve stability of the helix supply.

INSTALLATION

Upon receipt carefully unpack and inspect the instrument for damage received from transit. Should any damage be found, follow procedure outlined on "Shipment Damage Claim" page at the end of this manual.

This instrument is designed for either bench or rack operation in normal ambient temperatures. Air flow through the unit and from the solenoid exhaust should be completely unrestricted. Operation in the presence of very strong magnetic fields should be avoided unless external magnetic shielding is provided. Primary power requirements are 105 to 125 volts, 60 cps, approximately 620 voltamperes. If operation at other voltage or frequency is contemplated, consult manufacturer.

The Model 5-6752 is supplied with grey sheet metal sides containing recessed handles. If the instrument is to be rack mounted, the four screws on each handle side near the corners, and the screws at each edge of the panel, should be taken out and the sides removed. Screws for holding the sheet metal inside covers should be inserted in the holes. Unit is now ready for inserting into rack. Supports should be provided in the rack, to carry the weight of the Model 5-6752 upon its insertion or removal.

SETTING-UP PROCEDURE

The procedure outlined in this sub-section refers specifically to first-time operation of the unit. However, following a storage period, or after repair, the setting-up procedure should be repeated. Note that certain values of voltage and current have been written in. These pertain to TW Tube Serial No. 3479. Should the TW tube be replaced, the new operating values and tube serial number should be written in the appropriate spaces. The required information is on the data page supplied with each new tube. Proceed as follows:

1. Before turning on power, set panel controls:

   ANODE to 0
   HELIX to 620 v
   METER switch to HELIX

2. Turn on power and allow amplifier to warm up at least ten minutes.

3. Slowly turn up ANODE towards maximum value, noting that operating value of HELIX current should not exceed 6.7 ma.

   If HELIX current exceeds this value with below normal ANODE voltage, the TW tube probably requires mechanical realignment in its solenoid.

Alignment is accomplished by removing top and bottom perforated dust covers and adjusting TW tube positioning screws. Set screws that go in top and bottom, near center of solenoid ends are locking screws, and should be loosened before turning top and bottom positioning screws that go in at an angle near the edge. Also loosen TW tube clamp screws before adjusting. Orient TW tube to obtain the lowest HELIX current, all the while increasing ANODE voltage. ADJUST CAREFULLY. DO NOT DAMAGE TUBE CAPSULE BY CRUSHING IT AGAINST SOLENOID. AVOID HIGH HELIX CURRENT DURING ADJUSTMENT. Should helix current accidentally exceed 2 ma, overcurrent relay will shut off power supply. Operation can be restored by turning POWER switch off and then on again.

Positioning of the TW tube is most easily accomplished with two screwdrivers, one in each hand. Starting with the tube approximately in the center of the hole, slowly wobble the tube with the alignment screws to minimize helix current. Adjust alternately with both top screws, then both bottom screws, and perhaps one top and one bottom. After a minimum setting is reached, one screw should be turned, usually causing helix current to increase, and then the null relocated by turning a different screw. Often the new null is lower than the original. Reverse direction of turning if the new null is higher. Slight rotation and longitudinal positioning of the TW tube may also result in a lower minimum. With a little care, helix current usually can be reduced to a safe value.

Minimum helix current up to about 2 ma is safe. However, the lower the current, the less chance that gas will be driven from the helix due to high temperature operation. Gas would soon damage the cathode emission and render the TW tube inoperative. Lower current also reduces modulation of the RF output by beam noise and stray magnetic field.

4. When anode voltage can be set to maximum value with helix current at or below its operating value, change METER switch to CATHODE X10. Current should be slightly greater than the operating value of 4/5 ma. If not, ANODE CALIB. control requires resetting. Remove bottom dust cover and with ANODE control at maximum, set ANODE CALIB. adjustment near the right end and below the solenoid, to give approximately 2 ma above rated cathode current. Recheck helix current to assure it has not exceeded safe value.

   ANODE maximum is set for slight excess cathode current to allow for TW tube variation. However, ANODE should be set to give rated current or less during normal use. Excess current will overheat TW tube and may shorten its useful life.

5. Apply RF. Input power up to 100 milliwatts will not cause damage; however, only the normally required level of about a milliwatt should be used. If output can be observed, adjust,

if necessary, HELIX voltage slightly for optimum output. See, also, sub-section following, titled SYNCHRONISM. If RF output cannot be measured, connect a 1/2% or better accuracy voltmeter to rear HELIX VOLTAGE terminals and set HELIX voltage to measured value of exactly _____.

6. If possible, pulse or square wave modulated RF input should be applied and the amplifier output detected and observed on an oscilloscope. If significant 60 cycle modulation is noted, very slight repositioning of the TW tube in the solenoid may be required to null out stray magnetic fields from the power transformers in the instrument. Both helix current and ac field nulls occur at essentially the same mechanical positions, so the turning of one screw slightly, or small rotation of the TW tube, usually will give best modulation minimum without appreciably affecting helix current. Relock positioning screws, TW tube clamp screws, and replace dust covers.

7. Resetting of ANODE CALIB. control and a recheck of helix voltage, as described in 4 and 5 above, may be necessary after one hour, to correct for slight warmup drift. Position of HELIX control on panel should be noted so that it can easily be reset, should it accidentally be changed.

8. METER switch should be left in CATHODE X10 position during normal operation. An occasional check of helix current is recommended.

SYNCHRONISM

When the velocity of the electron stream and the progressive velocity of the RF signal are essentially the same, they are said to be in SYNCHRONISM. When operation at a single frequency is contemplated, helix voltage can be adjusted to synchronous value, to give maximum gain and output at that frequency. When operation over a wide bandof frequencies is contemplated, the helix voltage adjustment should be made to the factory-determined value. At this setting, synchronism usually occurs at some midband frequency. Even though other frequencies are off synchronism, rated broad band response results.

REPEAT OPERATION

1. Before turning power on, turn ANODE to zero.
2. Turn on power and allow ten minutes warmup.
3. With METER switch on HELIX, raise ANODE slowly to maximum value, noting that HELIX current should not exceed 63 ma. If too high, turn ANODE to 0 and follow SETTING-UP PROCEDURE.

REPEAT OPERATION (cont'd.)

4. Change METER switch to CATHODE X10 and note current slightly in excess of rated value, ___ ma. If incorrect, reset ANODE CALIB. control as indicated in 4 of SETTING-UP PROCEDURE. Reduce ANODE to obtain rated CATHODE current.

5. Recheck HELIX current.

6. Return METER switch to normal operating position of CATHODE X10.

7. Operation should now be normal. Should reoptimization of performance be required, follow SETTING-UP PROCEDURE.

OPERATION AS AN AMPLIFIER

Amplification is linear for RF output up to 6 db below maximum. Further increase beyond this level causes the output to flatten and then decrease. Operation in the region of maximum output is non-linear, causing appreciable distortion and harmonic content in the output signal. Gain may be adjusted using the ANODE control.

OPERATION AS A BUFFER

The Model 5-6752 can serve very effectively to isolate a microwave signal source from a load. Reflections from mis-matches, load variations, and the effects of modulation will not appreciably affect the impedance of the input terminals of the amplifier. The attenuator on the TW tube helix provides approximately 55 db attenuation between input and output, so load changes will be isolated from the source by this 55 db attenuation less the gain of the amplifier. The extreme case of a short or open circuit would be to change the VSWR of the amplifier input by about 7%.

OPERATION AS AN OSCILLATOR

The use of an external feed-back circuit involving a passive resonator such as a cavity, will permit use of the TW tube amplifier as an extremely stable fixed frequency or wide range oscillator. Oscillation results when total loop phase shift is in the vicinity of n x 360° producing positive feedback. This is accomplished by careful adjustment of helix voltage. Since helix voltage accelerates the electrons in the beam, it determines their velocity through the helix. Transit time and phase between output and input of the TW tube therefore varies with helix voltage. When a continually adjustable resonator is employed, it is necessary to optimize phase with the HELIX control progressively across the band. Otherwise, a series of oscillation modes will occur as phase of the TW tube amplifier rotates. A directional coupler or non-dissipative attenuator should be employed in the feedback line to minimize amount of output power fed to the input. This reduces harmonics and makes available almost all output power to drive a load.

SECTION IV - MAINTENANCE

GENERAL

CAUTION: Extremely dangerous high voltages exist in this instrument. Observe the utmost care when checking or making repairs.

Routine maintenance need consist of the following:

1. Check blower operation every three months or after 1000 hours use, and oil bearings with a few drops of light machine oil in the oil tubes provided. Regular attention to the blower is essential since its failure could result in damage to the TW tube from overheating.
2. Test at regular intervals the power supply tubes to detect marginal performance. Any voltage regulator tubes removed for test should be returned to their original sockets. INTERCHANGING OR REPLACING VOLTAGE REGULATOR TUBES WILL NECESSITATE RECALIBRATION OF HELIX SUPPLY VOLTAGE.
3. As TW tube ages, pre-set ANODE CALIB. control may require readjustment to maintain rated Cathode current when panel ANODE control is at maximum. The ANODE CALIB. control is located at the right of the instrument and below the solenoid.

CALIBRATION OF HELIX SUPPLY VOLTAGE

Calibration of helix supply voltage is accomplished by connecting a voltmeter having 1/2% accuracy or better to the Helix Voltage test points on the rear of the unit. Unlock the HELIX CALIB. control, located near the right end and below the solenoid. Move panel HELIX control over entire range and note readings. Adjust HELIX CALIB. control so that voltage indications are within 10 volts for any setting. Lock HELIX CALIB. control.

TROUBLE SHOOTING

Should a failure occur, follow a logical procedure to locate the cause. Refer, if necessary, to the Theory of Operation section and the schematic diagram includedin this manual. Blown fuses should be replaced with 250 volts 3 amp type 3AG for SUPPLY and 10 amp type 3AB for SOLENOID. Power supply tubes can be observed to determine if heaters are operating and voltage regulator tubes lit, by removing screws holding top dust cover and sliding it rearward. Operating voltages for the traveling wave tube may be measured as described below. Correct voltages are indicated on the circuit diagram.

Anode: Connect the negative lead of a high resistance dc voltmeter to Terminal 13 on TS1 (the terminal strip just rear of the panel), and the positive lead to Terminal 17.

TROUBLE SHOOTING (cont'd.)

Helix: Connect the negative lead of a high resistance dc voltmeter to terminal 13 of TS1, the positive lead to terminal 18.

Heater: Connect ac voltmeter to terminals 11 and 12 on TS1.

If tubes have been tested and found to be normal and supply voltages are incorrect, it is recommended that power be disconnected and faulty components located by a systematic resistance check.

All panel components are accessible by removing the panel screws near the handles.

All power supply components are accessible by removing rear plate.

BLOWER REPLACEMENT

Should blower fail or wear out, remove rear plate and top dust cover. Disconnect motor leads. Take out two screws holding motor and remove it from the housing. Normally, housing need not be disturbed; but if necessary, removing the mounting screws will free it from the instrument side. After servicing the blower, follow the above procedure in reverse to reassemble the instrument.

TRAVELING WAVE TUBE REPLACEMENT

To replace the traveling wave tube, take off grey handle sides by removing screws near corners and at edge of panel, and remove the left sheet metal cover. Unscrew the four screws on each of the panel type N RF connectors, and disconnect the power cable. Loosen TW tube clamp screws. Slide tube out hole in left side. TW tube positioning screws may have to be unscrewed to allow power connector to pass through solenoid.

Follow reverse procedure in installing the new tube. Observe due caution to prevent damaging the tube. Follow SETTING-UP PROCEDURE in OPERATION section, except that new values of operating voltage and current supplied with the replacement tube should be substituted for the original values. Since ANODE CALIB. control will require resetting during mechanical alignment of the tube, cathode current should be checked to assure rated value is not appreciably exceeded as ANODE control is increased.

To permit rotation of the TW tube for best alignment, RF leads may be temporarily brought out through the hole in the cover side.

TRAVELING WAVE TUBE REPLACEMENT (cont'd.)

Do not allow excessive air leakage during adjustment. When alignment is complete, install RF leads through holes in air manifold fiber piece, and RF connectors on panel.

TRAVELING WAVE TUBE WARRANTY

All workmanship and materials, except the traveling wave tube, are guaranteed for one year. Details concerning warranty adjustment are presented on "Shipment Damage Claim" page at the end of this manual.

The traveling wave tube is guaranteed for 500 hours use or one year, whichever occurs first. Cost of an in-warranty replacement traveling wave tube will be pro-rated according to tube life obtained or time from delivery, whichever is greater. Warranty requests should include a description of the failure, factors leading to it, and an accurate estimate of operating hours.

MODEL 5-6752
TWT SUPPLY CHECK
Serial No. 25

HELIX-COLLECTOR, @ 115 v, 50 ma

E min. + 500 v (490-510) E max. + 808 v (784-816) Ripple 10 mv pk to pk (< 50)

Calibrates within 2% ✓ OK

E input min. 98 v @ max., 50 ma (< 105)

ANODE @ 115 v input

E max. + 762 v (Anode Calib. Max.) (> 750) @ 0 ma Ripple 200 mv pk to pk (< 500)

E max. 0 v (Anode Calib. Min.) (< 5) @ 0 ma

6146 SCREEN @ 115 v input

E 138 v (130-145) Ripple 0.15 v pk to pk (< 2)

SOLENOID @ 115 v

E 91 v (85-95) Ripple 0.8 v pk to pk (< 1)

TW TUBE HEATER

E 6.53 v AC @ 105 v input, 5 Ω load (6.3-6.6)

E 6.53 v AC @ 125 v input, 5 Ω load (within 0.12 of 105 v value)

HELIX OVERCURRENT RELAY

Trips at 1.7 ma (1.5-2.3)

Checked by W.H.V. & H.K.

Date 1-2-59

SYLVANIA ELECTRIC PRODUCTS INC.
Microwave Tube Laboratory
Mountain View, California

Sylvania Type TW-620B Serial No. 3474 Date 3-23-59

BASE PLUG: Winchester PM6P

R-F CONNECTORS: Gremar #5267

BASE CONNECTIONS:

A. NC
B. Anode
C. Helix
D. Cathode, Htr.
E. Heater
F. Capsule, Collector

ELECTRICAL DATA:

Heater.....	6.3 V	1.20 A
Anode.....	380 V	—
Helix.....	620 V	0.8 mA
Collector.....	150 V (above helix)	~~38.0 mA~~
Magnetic Field....	600 Gauss	

R-F CHARACTERISTICS

P in = 1 mw

Freq. kmc/s	P_o Watts	Gain db
1.0	3.4	35.3
1.2	2.6	34.2
1.4	2.8	34.5
1.6	4.0	36.0
1.8	4.2	36.2
2.0	3.3	35.2

NOTES:

1. All voltages are with respect to cathode, except where noted.
2. Collector electrode is connected internally to capsule and must be operated at ground potential to keep dangerous voltage off capsule and solenoid.
3. Solenoid should be connected to ground.
4. Helix optimized at 2 KMC

Signed: [illegible]

Signed: [illegible] 3-23-59

HELIX OVERCURRENT RELAY

RY-2
POWELS
TEX

TS-1

CAPSULE

B-1
BLOWER
115VAC

P-2

S-1

SOLENOID

TW TUBE AMPLIFIER
MODEL 5-6752
SERIAL 15 & UP 900109B

DRAWN
R.F.H.

CHECKED

APPR'D

HUGGINS LABORATORIES
ENGINEERING NOTES
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GENERAL INFORMATION ON TRAVELING-WAVE TUBES

Introduction

Engineers who design and build circuits which use conventional low frequency vacuum tubes usually have at least a speaking acquaintance with the theory upon which these tubes operate. In designing their circuits or in deciding which type of tube to use, careful use is made of the various characteristic curves associated with the tubes. It is the purpose of the following brief discussion to similarly acquaint the applications engineer with the simple theory of the operation of the traveling wave tube and to familarize him with the various characteristic curves which describe its operation. From this discussion, it is hoped that the data sheets contained in this catalog may take on added meaning and that a better understanding of the basic functions of the traveling wave tube may be obtained.

Microwave Amplification

As the microwave region of the radio frequency spectrum has come into practical engineering use, engineers have been constantly on the lookout for devices which could function as better amplifiers and oscillators. In the frequency range above a few hundred megacycles conventional vacuum tubes no longer amplify properly because the period of one cycle of the radio frequency wave approaches the time it takes the electrons to travel from cathode to anode within the tube. As a result the amplification factor of the tube decreases with increasing frequency until no useful gain can be obtained. This is known as the transit time effect.

The first devices which served as practical amplifiers above a few hundred megacycles actually made use of transit time effects. These devices are known as klystrons and became useful primarily as oscillators although they are also capable of acting as amplifiers. Klystron amplifiers are capable of giving high values of amplification, but they have one serious limitation for many applications. They are relatively narrow band devices; having usually no more than a few megacycles bandwidth between half-power points. Tuning of the amplifier to different frequencies requires a mechanical adjustment. The klystron is, however, the forerunner of a whole general class of microwave electron devices which utilize transit time effects in electron beams. This general class of devices includes the traveling wave tube.

A klystron is a narrow band device because it involves the use of a very sharply resonant, high-impedance tuned circuit. It is necessary for a klystron to use such a circuit because interaction takes place with the electrons over only very short

physical distances and it must develop high electric fields to have efficient interaction with the electrons. However, it was reasoned that one might obtain a very broadband amplifying device if one used a low-impedance, broadband circuit which developed relatively small electric fields but which interacted with the electrons over a long physical distance. Such is the basis on which the traveling wave tube works and this basic concept has led to a wide range of devices which are useful as broadband amplifiers and oscillators in the microwave region.

The traveling wave tube is basically capable of giving high values of amplification over wide frequency ranges without requiring the change of any mechanical tuning mechanism or the variation of any voltages or currents applied to the tube. Power amplification greater than 10,000 (ie., 40 db gain) over a 2:1 frequency range has been obtained with this type of tube. The actual number of megacycles covered by such tubes can be a staggering figure. An operating bandwidth of 2000 megacycles has been obtained in one typical tube type; 7000 megacycles has been obtained in another.

Tubes can be built which emphasize various special characteristics. For instance, tubes can be built which have low noise properties, or high power output, or controlled variations of gain with frequency. Many special tubes have been designed and built for particular applications.

Simple Description of Theory of Operation
(Forward-wave Helix Type Amplifier)

One of the simplest circuit elements which satisfies the broadband low-impedance circuit requirement of the traveling wave tube is a simple helical transmission line. On this so-called helix, the radio frequency energy essentially travels at the velocity of light along the wire from which the helix is wound. But since the wire and the energy follow this helical path, the actual progress of the energy along the axis of the helix is at some fraction of the velocity of light. This velocity is determined by its dimensions (ie., its circumference and pitch) and by the dielectric loading due to the structure which supports the helix. The fields associated with this "slow-wave" extend outward and inward into the regions adjacent to the helix and it is into these regions that electrons are sent to interact with the waves.

If electrons are sent along the axis of the helix at essentially the same velocity as the waves, an interaction between waves and electrons occurs wherein the electrons become bunched and then become packed into tighter and tighter bunches as the electrons progress down the helix. Simultaneously, the radio frequency fields on the helix increase in magnitude as they progress down its length. The increase in energy of this "growing wave" is just balanced by a decrease in the average kinetic energy of the electrons in the beam. In other words, the electrons on the average have been slowed down and have given up just enough energy by this slowing down process to account for the increasing energy or power level in the waves on the helix.

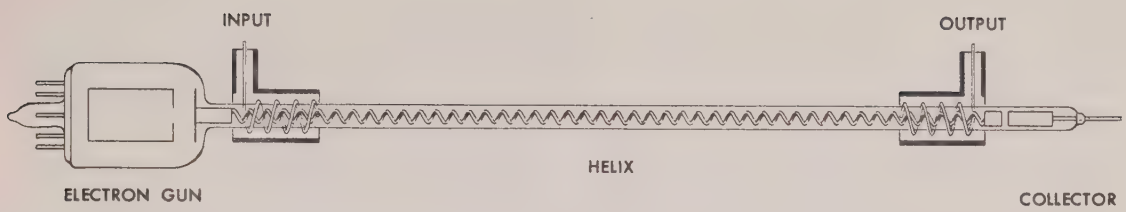

FIG. 1

Schematic View of Traveling-Wave Tube

In practice, the electron beam is formed in a gun and is focused down the center of the helix to a collector electrode on the farther end (see Figure 1). The velocity of the electrons is determined by the voltage difference between the cathode in the electron gun and the helix, and this is adjusted to give the electrons just the right velocity for interaction with the waves. The signal to be amplified is coupled onto the end of the helix nearest the electron gun and propagates along the helix in the same direction as the electron beam. Because of the interaction, the fields on the helix grow exponentially with distance and these amplified waves are coupled off of the helix at the end farthest from the electron gun. The devices which couple the energy on and off the helix at its beginning and end are connected to the input and output transmission lines. The electron beam that is formed in the gun is maintained in a tight pencil beam throughout the length of the tube by the confining forces of a longtitudinal magnetic field which surrounds the tube.

The devices which couple the energy onto and off of the helix are special directional couplers which are in themselves helices. These helices, which are outside of the vacuum envelope of the tube, are matched to the input and output coaxial transmission lines. They are capable of transferring most of the energy from the lines to the main helix, which is inside the vacuum envelope, without having to make physical contact to the helix. These "coupled helix matches" have the additional advantage that they have very wideband transfer characteristics and are capable of presenting a standing-wave ratio to the coaxial transmission line of 1.5:1 or less.

Specific Characteristics

In the following sections, the various characteristic curves that are encountered in operation of the traveling wave tube are shown and discussed.

Helix Voltage vs. Frequency

Usually a helix will be designed such that the "slow-waves" travel at a velocity in the range of 1/10 to 1/30 of the velocity of light. If the velocity of the waves is examined as a function

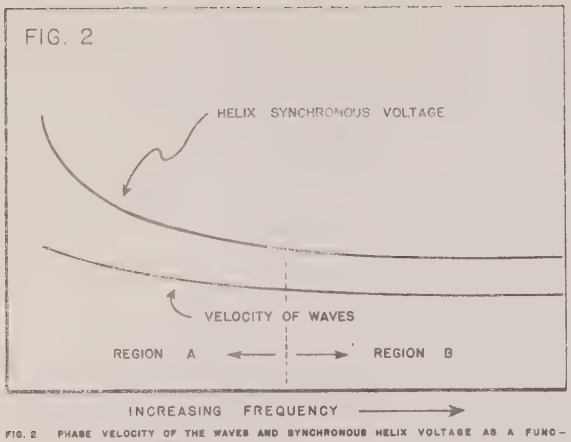

FIG. 2 PHASE VELOCITY OF THE WAVES AND SYNCHRONOUS HELIX VOLTAGE AS A FUNCTION OF FREQUENCY.

of frequency it is found a helix will have a general characteristic curve similar to that shown in Figure 2.

There is a region A where the velocity of the waves varies as a function of frequency, and there is a region B where the velocity of the waves is essentially independent of frequency. It is in this region B, known as the "non-dispersive region", where a broadband amplifier is normally operated.

As mentioned before, it is necessary to have the electrons travel down inside the helix at essentially the same velocity as the waves (synchronous velocity) in order to obtain the growing wave interaction. Thus if the velocity of the wave varies as a function of frequency, the velocity of the electrons must also be varied so that interaction is maintained. Since the velocity of the electrons is determined by the voltage difference between the cathode and the helix, there is also a characteristic curve of synchronous helix voltage as a function of frequency which is shown in Figure 2.

The reason why a helix type traveling wave tube can amplify over wide bandwidths without changing helix voltage can now be easily seen. In the region B, the non-dispersive region, the synchronous voltage of the electrons is essentially independent of frequency. That is, the helix voltage which gives the desired interaction between the waves and electrons can be fixed at one value and this will be the correct value to provide interaction and amplification over a wide range of frequencies.

Gain vs. Helix Voltage

To obtain the greatest interaction between the waves and the electrons and thus the greatest amplification, the helix must be operated at synchronous voltage. If the helix voltage is varied away from synchronism, the gain will decrease as shown by the curve in Figure 3 which is parabolic in shape.

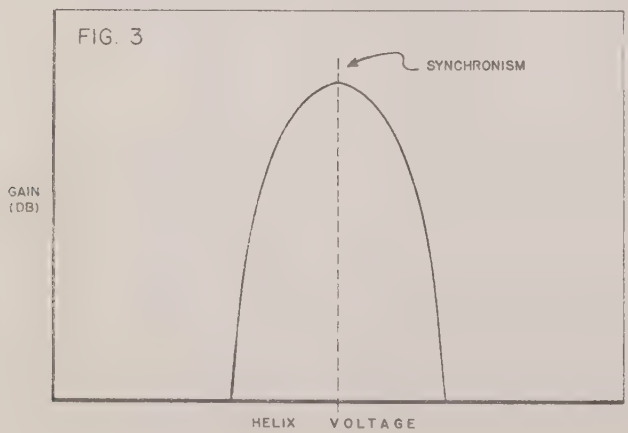

FIG. 3 GAIN AS A FUNCTION OF HELIX VOLTAGE.

Gain and Power Output vs. Frequency

Figure 4 shows a typical plot of gain vs. frequency for a fixed value of helix voltage. Small signal gain is obtained

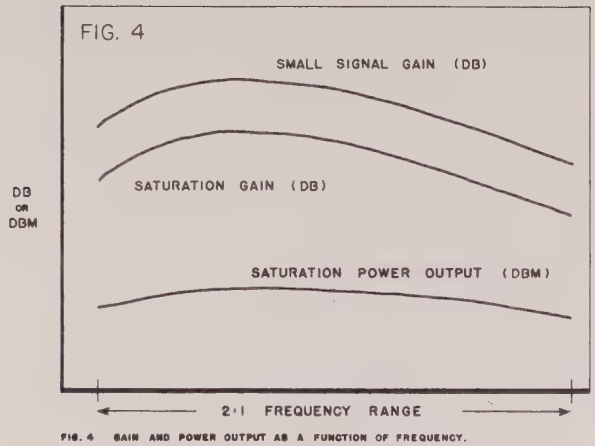

FIG. 4 GAIN AND POWER OUTPUT AS A FUNCTION OF FREQUENCY.

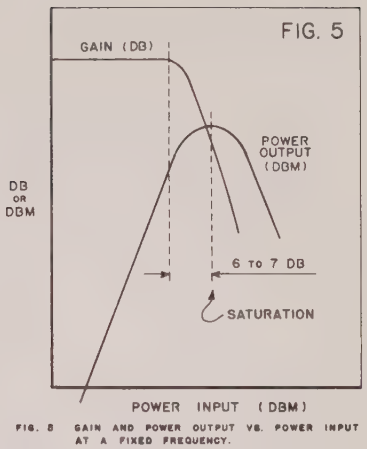

FIG. 5 GAIN AND POWER OUTPUT VS. POWER INPUT AT A FIXED FREQUENCY.

for all values of input signal level except those which drive the tube near its maximum or saturation power output. Saturation gain is the gain obtained when the tube is driven to its maximum or saturation power output. It is seen that the gain and power output curves generally have a maximum near the center of the band and that the curves droop off towards the band ends.

Power Output and Gain vs. Power Input

Figure 5 shows a typical variation of power output and gain vs. power input at a fixed frequency. The amplifier is linear until power input is within 6 to 7 db of the value which drives the amplifier to saturation. At this point the power output curve begins to droop over, and gain of the tube begins to decrease. At saturation the power output is a maximum and the gain has decreased to a value which is called saturation gain. As the tube is driven beyond saturation the power output drops off and gain continues to decrease. To obtain maximum power output from an ordinary traveling wave tube, just the right amount of power input must be applied. The saturation region does not exhibit the leveling off or flat saturation characteristic that is found in conventional low frequency amplifier tubes.

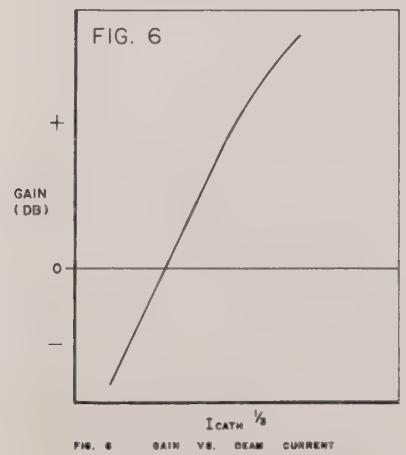

FIG. 6 GAIN VS. BEAM CURRENT

Gain vs. Beam Current and Grid Voltage

Figure 6 shows that the gain at any fixed frequency is essentially a function of the 1/3 power of the beam current and decreases as beam current is decreased. Figure 7 shows that as the grid electrode is made negative with respect to the cathode, the gain of the tube decreases. This results from the fact that operating the grid negative with respect to the cathode causes the beam current to decrease.

If the beam current is decreased below a certain value as shown in Figure 6, the gain of the tube measured in db becomes

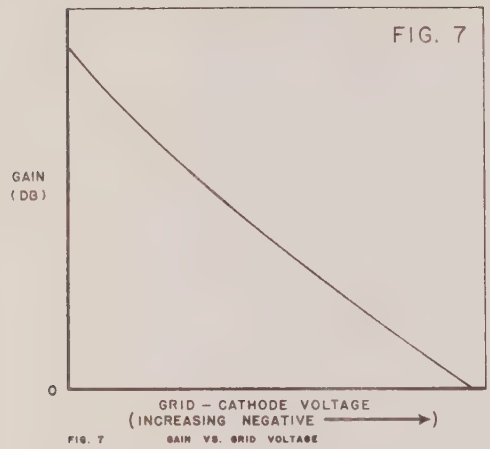

FIG. 7 GAIN VS. GRID VOLTAGE

negative, ie., the tube is acting as an attenuator. If the beam current is reduced to zero, the net "cold" attenuation of the tube is available. The total change in signal output level as beam current is decreased from its normal value to zero is equal to the sum of the net gain of the tube plus the cold attenuation. This can approach a variation in signal level of about 100 db. This is accomplished merely by varying the control grid voltage.

Special Characteristics

Low Noise Amplifiers

On a typical low power amplifier one may find a noise figure of 20 db. Certain applications require lower noise figures than this. Techniques are available in electron gun design whereby the "shot noise" in the beam can be "de-amplified" before it reaches the beginning of the helix. Special purpose tubes built in this fashion have reached noise figures as low as 6 db.

Narrow Band Amplifiers

Where an application does not require extremely wide bandwidths, tubes have been built which operate in the dispersive region of the tube characteristics where the velocity of the waves varies as a function of frequency (see Figure 2). In this region operation at a fixed voltage leads to amplification over only a relatively narrow band of frequencies. Extremely high values of gain (eg. 60 to 70 db gain) have been obtained because the problem of controlling spurious oscillations is much simplified since the tube exhibits gain over only a relatively narrow band.

Special Gain Variation

Sometimes special requirements are imposed on the gain variation of the tube as a function of frequency. Tubes have been built which exhibit an essentially constant value of gain across the band. Others have been built which have linearly increasing gain with frequency. Various other combinations are also possible.

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MEASUREMENT TECHNIQUES

As traveling wave tubes have come into more common use, the need has become apparent for a clarification of the various measurement techniques involved in an evaluation of the tube characteristics. Since the traveling wave tube is a very broadband device the emphasis must be upon broadband, untuned measuring techniques and test equipment. Otherwise, much time will be lost in the repetitive and laborious adjustment and tuning of narrow band devices to make point by point measurements across wide frequency ranges.

It will be noticed that the emphasis on measuring equipment has been placed upon coaxial systems. This is done, obviously, because of the inherent wideband properties of coaxial test equipment. Waveguide equipment is used only where equivalent coaxial equipment is not available or will not do an equivalent job.

The various types of broadband test equipment commonly used are listed below:

1. Self-tracking tunable signal generator with calibrated power output.
2. Untuned coaxial crystal detector.
3. Untuned coaxial bolometer or thermistor mount with self-balancing power bridge.
4. Broadband coaxial fixed attenuator.
5. Coaxial switch (SPDT).
6. Coaxial slotted section (for VSWR measurement) with untuned detector.
7. Coaxial or waveguide directional coupler.
8. Fluorescent noise source.

The characteristics to be measured comprise essentially the following list.

1. Gain
2. Power Output
3. Standing Wave Ratio or Reflection Coefficient
4. Insertion Loss
5. Noise Figure

PROCEDURES

A. Measurement of Gain

The most rapid and satisfactory method of measuring gain is to make an insertion gain measurement using the substitution method. This method does not require a knowledge of the detector characteristics nor an absolute power calibration of the signal generator. Its accuracy depends only upon the calibration accuracy of the output attenuator of the signal generator.

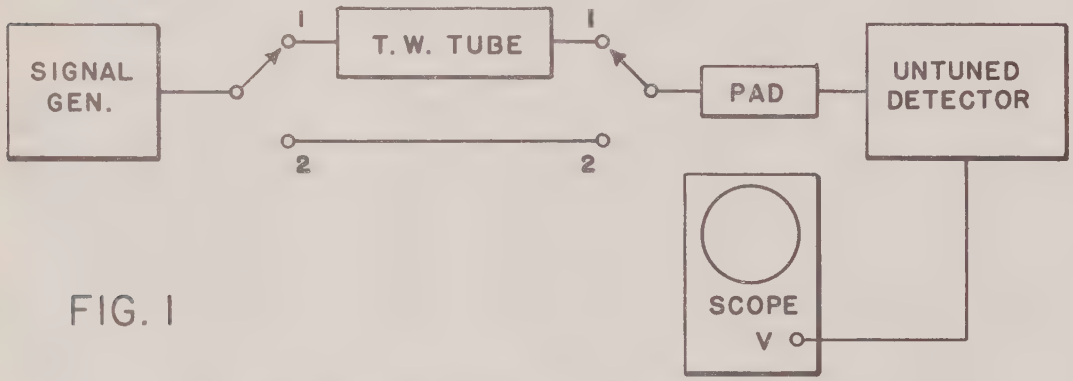


FIG. 1

BLOCK DIAGRAM OF GAIN MEASUREMENT SET-UP

As shown in the block diagram of Figure 1, the output of the signal generator (which has a matched 50 ohm output) is fed to the input of the tube through a coaxial single-pole double-throw switch. The output of the tube is fed through another coaxial switch and at least a 6 db coaxial fixed attenuator pad to the untuned detector. The pad can be eliminated if the detector is matched. The output of the detector is fed to the vertical deflection channel of an oscilloscope. The tube is by-passed when the switches are thrown to the other position.

Procedure:

Apply pulse or square wave modulation to the signal generator. With the tube operating and the switches in position 1, the output attenuator of the signal generator is adjusted to give some convenient deflection on the scope. This is attenuator reading 1. The switches are then thrown to position 2 and the attenuator readjusted to give the same deflection on the scope. This is attenuator reading 2. The insertion gain of the tube is then the difference of the attenuator readings 1 and 2 measured in db.

Precautions:

1. Both the signal generator and the detector must present good impedance matches as seen by the switch. If they are not matched, then reflection losses can give up to several

db error in gain. This is the reason for the pad ahead of an unmatched detector. A 6 db pad guarantees a VSWR of at most 1.5:1.

2. The switch used must have a low VSWR and very low crosstalk. Crosstalk is the stray feedthrough from input terminal to output terminal of the DPDT switch combination through the unused channel of the switch. Crosstalk ratio is measured by disconnecting the tube from terminals 1, and measuring the difference in signal generator attenuator reading with the switches in position 1 and position 2 for the same deflection on the scope. This crosstalk ratio should be at least 20 db greater than the gain of the tube to be measured. This prevents regenerative feedback around the switch which will give errors in gain measurement. If the crosstalk ratio is greater than about 45 db, it probably cannot be measured with the setup of Figure 1. See section D on insertion loss measurement.

3. If small signal gain is to be measured, care must be taken that the output power level of the tube is at least 10 db below the saturation power level. This eliminates errors due to the decreasing gain characteristic of the traveling wave tube in the region near saturation.

B. Measurement of Power Output

When power measurements are to be made over wide frequency ranges, it is convenient to use broadband (untuned) bolometer or thermistor mounts as power detectors. When these mounts are operated in conjunction with a self-balancing wattmeter bridge they provide a convenient system for the measurement of absolute power.

If the power level to be measured is greater than the maximum allowable power input to the mount, then it is necessary to insert a calibrated attenuator pad ahead of the mount. The most convenient type of pad to use is the resistive film type which has attenuation characteristics which are essentially independent of frequency. Care must be taken not to exceed the maximum input rating of the attenuator.

If power levels to be measured are greater than the rated dissipation of standard attenuator pads, then a directional coupler must be placed on the output of the tube. The main arm of the coupler is terminated with a broadband load and the power detector with appropriate pads is placed in the auxiliary arm of the coupler. Broadband coaxial directional couplers with coupling ratios of 10 and 20 db from main arm to auxiliary arm are available.

If gain measurements are to be made in conjunction with the power measurements then the power output of the signal generator must be calibrated using its power monitor at each

frequency. For the sake of accuracy, the power output reading of the signal generator should be initially checked using the bolometer mount and the wattmeter bridge at least over the range of power levels that the bridge can accurately read. If care is taken to check the calibration of the attenuator pad and the signal generator, then the small signal gain measurements obtained with this equipment should check with small signal gain measurements made by the method of section A.

If all power measurements are recorded in terms of dbm (ie., db with respect to one milliwatt), then the readings of the power bridge, the attenuator (in db) and the signal generator need be merely added and subtracted to obtain power output and gain. Conveniently, most signal generators and power bridges are calibrated in dbm as well as milliwatts.

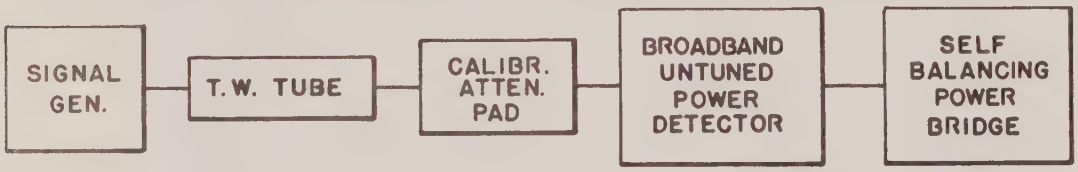


FIG. 2 BLOCK DIAGRAM OF POWER MEASURING SET-UP

Figure 2 shows the block diagram of the power measurement setup. The power output is then given by the equation:

$$P_{out}\ (dbm) = \text{Pad Attenuation (db)} + \text{Ratio of Directional Coupler (db)} + \text{Power Bridge Reading (dbm)}$$

The gain of the tube is given by the equation:

$$\text{Gain (db)} = P_{out}\ (dbm) - P_{in}\ \text{from Sig. Gen. (dbm)}$$

The above gain measurement is valid not only for small signal gain, but also for gain measured in the saturation region and beyond.

C. Measurement of Standing-Wave Ratio or Reflection Coefficient

For direct measurement of Voltage Standing-Wave Ratio (VSWR) the coaxial slotted line is the simplest. To speed up broadband measurements, however, it is essential to have an untuned detector on the slotted line.

For situations where it is necessary to examine the VSWR continuously over a wide frequency range and where fast checks are required such as on production test setups, the slotted line type of measurement becomes prohibitively time consuming and laborious. For such situations, the measurement of reflection coefficient through the use of directional couplers is recommended. Two directional couplers connected so that one will give an output proportional to the incident wave and the other an output proportional to the reflected wave from the

load can be used. These two outputs can be detected and compared with a ratiometer to give a direct reading of reflection coefficient. The reflection coefficient can be converted to equivalent VSWR if necessary. The higher the accuracy required in the measurement of reflection coefficient, the higher the directivity of the directional couplers must be. In waveguide, directivity greater than 40 db over the waveguide range can be obtained which allows measurement of reflection coefficient of 0.1 with an accuracy of plus or minus .02. This means that a load VSWR of 1.2 will give an indicated reading between 1.15 and 1.25. A waveguide to coaxial transition can be used to adapt the reflectometer to coaxial systems. In this case, the residual reflection in the transition limits the accuracy at low VSWR.

Using such a reflectometer setup, once the initial calibration is performed it is necessary only to tune the signal generator across the frequency range and the reflection coefficient values read directly. An excellent detailed discussion of this method, its errors and limitations, is given in the Hewlett-Packard Journal, Volume 6, Number 1-2, Sept.-Oct., 1954.

Even faster measurements can be made when a swept oscillator is employed. Reflection coefficient can be displayed directly on a scope as a function of frequency and the measurement can be made at a glance.

D. Measurement of Insertion Loss

It is often necessary to measure insertion loss in the range of 40 to 100 db (eg., the measurement of the cold loss of a traveling wave tube) over a wide range of frequencies. Such a measurement cannot be made with 1 milliwatt signal generator and a broadband detector as this type of system does not have the power levels nor the sensitivity to measure much more than 45 db insertion loss. Such a wideband measurement can be made quickly and easily with the use of one or two traveling wave tubes as amplifiers. Use of a traveling wave tube with a noise figure of 20 db ahead of the detector gives a sensitivity into a broadband detector of the order of -65 to -75 dbm. This alone allows the measurement of insertion loss of 65 to 75 db. Further, if the output of the signal generator is amplified to the power level of one watt (+ 30 dbm) by the use of a medium power traveling wave tube, the total insertion loss then measurable becomes 95 to 105 db. The only adjustment necessary as frequency is changed across the band is the tuning of the signal generator since the traveling wave tubes are broadband untuned devices. The insertion loss measurement can be made in the same manner as the insertion gain measurement shown in Figure 1 except for the addition of the amplifiers before and after the switches. Commercially available switches when connected as shown in Figure 1 have been measured to have a combined crosstalk ratio in excess of 120 db which, of course, eliminates any crosstalk error in insertion loss measurements in the range of 95 to 105 db.

E. Measurement of Noise Figure

Where one is interested in measuring noise figure at a number of frequencies throughout a wide frequency band, the best method employs a fluorescent tube noise source and a superheterodyne receiver with a second detector which is square law (ie., a power detector). If noise figure does not vary too rapidly with frequency, a simple receiver can be used which employs only an untuned crystal mixer, a local oscillator, a 30 mc I.F. strip and a power detector. Note that no preselection or mixer tuning is used. Without a preselector, the receiver will respond equally well to the signal frequency and to the image frequency. With a 30 mc I.F. amplifier, these two frequencies will be only 60 mc apart, and if noise figure is not a rapid function of frequency then the measured noise figure will be an average of the true values at two frequencies 60 mc apart. This is accurate enough for most purposes. If noise figure varies so rapidly that it will be appreciably different at two frequencies spaced 60 mc, then preselection is necessary.

The noise figure of an amplifier is defined as the ratio of signal to noise ratio at the input of the amplifier to signal to noise ratio at the output of the amplifier.

$$N.F. = \frac{(S/N)in}{(S/N)out} \quad \text{(power ratio)}$$

When the measurement is made according to the method outlined below, using a noise source whose level is 15.8 db above thermal noise, the above equation becomes:

$$N.F. = \frac{37k}{\frac{P_1}{P_2} - 1} \quad \text{(power ratio)} \qquad (1)$$

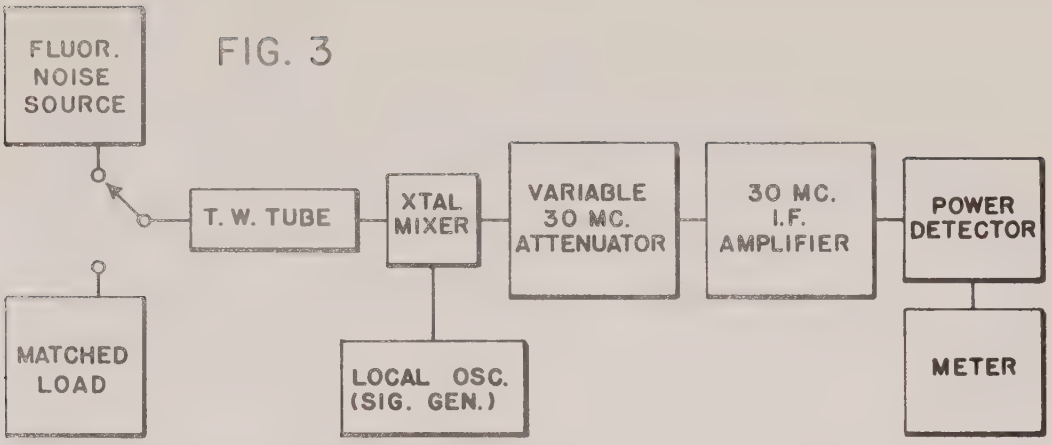
where P_1 and P_2 are defined in the measurement procedure below.
k is a number smaller than 1.0 which accounts for any cable loss between the noise source and the tube. It is the cable loss in db converted to a power ratio. (eg., for cable loss = 1 db, k = .794)

When a fluorescent noise source is used it is not necessary to know the effective RF noise bandwidth of the receiver.

Procedure:

The tube to be measured is connected into the setup shown in Figure 3. The power detector in the receiver may take the form of a bolometer or a thermistor operating into a self balancing wattmeter bridge, or it may be a thermocouple whose output is connected to a microammeter.

FIG. 3



SET-UP FOR MEASURING NOISE FIGURE

1. With tube operating and local oscillator tuned to the desired frequency, switch tube input to the fluorescent noise source.

2. Adjust variable 30 mc attenuator until the reading on the output meter is approximately full scale. This is reading P_1.

3. Switch tube input to the matched load. The reading of the output meter is P_2.

4. Insert values for P_1 and P_2 in equation (1) for noise figure. Noise figure in db is obtained by merely converting this number to db.

Precautions:

The accuracy of this measurement is based upon the assumption that the receiver is linear. This will be true if the local oscillator signal is large enough to produce linear mixing and if the I.F. amplifier is operated in the linear portion of its characteristics.

The measurements should be taken quickly enough so that power meter drift will not effect readings.

-- L. A. Roberts

SHIPMENT DAMAGE CLAIM

The instrument should be tested as soon as it is received. If it fails to operate properly or is damaged in any way, a claim must be filed with the carrier. Have carrier agent inspect damage to instrument and packing crate and forward to us a copy of his written report. You will then be advised of replacement or repair arrangements and disposition of the equipment. Please include model number, type number and serial number when referring to this instrument for any reason.

WARRANTY

ALFRED ELECTRONICS warrants each instrument manufactured by them to be free from defects in material and workmanship. Our liability under this warranty is limited to servicing or adjusting any instrument returned to the factory for that purpose and the replacing of any defective parts. This warranty is effective for one year after delivery to the original purchaser when the instrument is returned, transportation charges prepaid by the original purchaser, and which upon our examination is disclosed to our satisfaction to be defective. If the fault has been caused by misuse or abnormal conditions of operation, repairs will be billed at cost. In this case an estimate will be submitted before the work is started.

If any fault develops:

1. Notify us, giving full details of the difficulty, including the model number, type number and serial number. Upon receipt of this information you will be sent service instructions or shipping data.

2. Upon receipt of shipping instructions forward the instrument prepaid, and repairs will be made at the factory. If requested, an estimate of the charges will be made before the work begins when instrument is not covered by this warranty.

PACKING

The instrument should be packed in the original carton. If unusable or not available, use a wooden box with approximately three inches of excelsior or other shock-absorbing material surrounding the instrument. If desired, packing services of a local Transfer and Storage company may be employed.